COMPUTERIZED SEGMENTATION OF SINUS IMAGES

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By

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DISSERTATION

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CERTIFICATION OF APPROVAL

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Approved:

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Project Supervisor
Ms Lila Iznita Izhar

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
June 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Lee San Nien

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This project would not have been possible without the help of a few important people and I would like to express my gratitude to all of them.

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ABSTRACT

Sinusitis is currently diagnosed with techniques such as endoscopy, ultrasound, X-ray, Computed Tomography (CT) scan and Magnetic Resonance Imaging (MRI). Out of these techniques, imaging techniques are less invasive while being able to show blockage of sinus cavities. However, the potential of these techniques have not been fully realized as the images obtained are still bound to misinterpretations. This work attempts to solve this problem by developing an algorithm for the computerized segmentation of sinus images for the detection and grading of sinusitis. The image enhancement techniques used were median filtering and the Contrast Limited Adapted Histogram Equalisation (CLAHE). These techniques applied on input images managed to reduce noise and smoothen the image histogram. Multilevel thresholding algorithms were developed to segment the images into meaningful regions for the detection of sinusitis. These algorithms were able to extract important features from the images. The simulations were performed on images of healthy sinuses and sinuses with sinusitis. The algorithms are found to be able to detect and grade sinusitis. In addition, a 3-D model of the sinuses was constructed from the segmentation to facilitate in surgical planning of sinusitis.

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LIST OF ABBREVIATIONS

2-D	2-Dimensional
3-D	3-Dimensional
CT	Computed Tomography
CLAHE	Contrast Limited Adaptive Histogram Equalization
GHE	Global Histogram Equalization
HE	Histogram Equalization
MRI	Magnetic Resonance Imaging

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Sinusitis is the inflammation of the sinus cavities, which are the moist, hollow spaces in the bones of the skull. There are four pairs of sinuses in the skull, namely the frontal sinuses, the maxillary sinuses, the ethmoid sinuses and the sphenoid sinuses. Figure 1 (adapted from [1]) and Figure 2 (adapted from [2]) show the location of the sinuses.

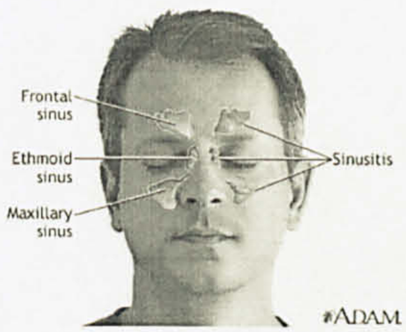


Figure 1: The frontal sinus, ethmoid sinus and maxillary sinus

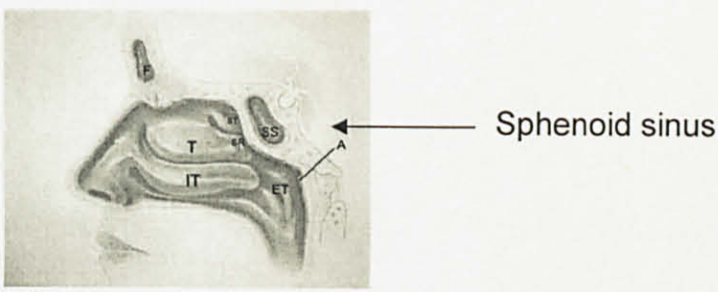


Figure 2: The sphenoid sinus

Inflammation can be caused by bacteria, viruses, fungi and allergies [3]. When inflammation happens, the mucosal lining produces more mucous than usual [4]. The pressure inside the sinus cavities builds up, thus causing inflammation and pain [1].

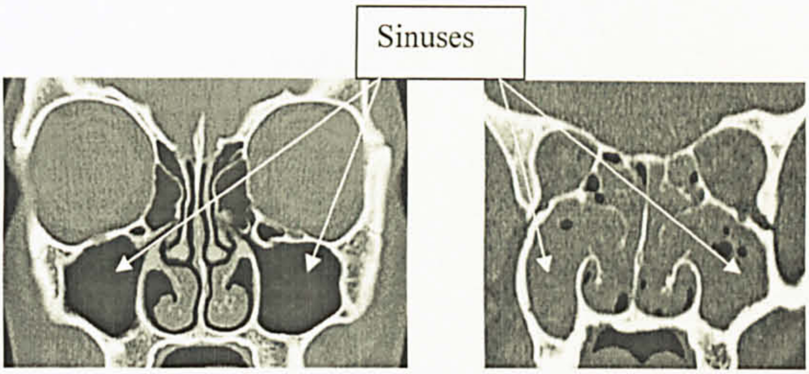
There are two types of sinusitis; acute and chronic sinusitis. Acute sinusitis happens and stays for less than three weeks. If sinusitis attacks for more than three weeks, this condition is called chronic sinusitis [3]. Acute sinusitis is normally caused by viral infection. Causes of chronic sinusitis include allergy, environmental factors such as dust and pollution, bacterial and fungus infection [5].

Sinusitis causes pain in areas above or below the eyes [6], pain in the teeth and above the cheek, pain in the forehead or pain in the temple [4], depending on the type of sinusitis. Patients with sinusitis perceive themselves to have worse health than do angina sufferers [8]. It is estimated that 1% or 2% of adults have lost their sense of smell and taste due to sinusitis [9].

The prevalence rate of sinusitis refers the estimated population of people who are managing the disease at any given time. In the United States, the prevalence rate is approximately 1 in 7, or 13.60%, or 37 million people [10]. These statistics were extrapolated to get the estimated prevalence rate of sinusitis in other countries and regions. The estimated prevalence rate in Malaysia based on this calculation is 3,199,749 people, or approximately 12.80% [10]. Therefore, at any one time, around three million people in Malaysia are affected by sinusitis.

Treatment of sinusitis aims to improve drainage of mucus and reduce swelling in the sinuses, relieve pain and pressure, clear up any infection, prevent the formation of scar tissue and avoid permanent damage to the tissues lining the nose and sinuses. Medications are used when sinusitis is caused by bacterial infection. Chronic sinusitis require longer period of treatment. Surgery is carried out if sinusitis cannot be treated with drugs.

In some cases, imaging techniques are helpful in detecting sinusitis in uncertain or recurrent cases [6]. X-rays, CT scan and MRI are used to give impressions on sinuses. Unfortunately, X-rays and MRI images do not give an accurate picture of the sinuses [10]. However, some doctors find CT scan images helpful [10], therefore CT scan is more commonly used than X-ray and MRI for the detection of sinusitis. CT scan is able to give clinicians an impression of sinusitis. Figure 3 (a) shows a CT scan image of a healthy patient with healthy sinuses while Figure 3 (b) shows a CT scan image of a patient with sinusitis.



(a) (b)

Figure 3: (a) CT scan image of healthy sinuses (b) CT scan image of sinus with sinusitis

Sinusitis is suspected when the sinus areas are filled with mucous. Refering to Figure 3 (b), mucous is present in the sinuses as indicated by the grey areas in the sinuses. The grey areas are not present in the image of healthy sinuses in Figure 3 (a). The sinuses are clear, as indicated by black areas instead of grey areas.

1.2 Problem Statements

The two main problems associated with the detection of sinusitis using sinus images are the difficult diagnosis of sinusitis itself and the problems with manual segmentation of sinus images. Sinus images can be obtained via X-ray scan, CT scan and MRI scan.

Sinusitis can sometimes be difficult to diagnose as it shares similar symptoms as common cold. Within the illness itself, physicians need to differentiate between bacterial, fungal or chronic sinusitis. Studies performed in primary care settings indicate that no single symptom or sign is both sensitive and specific for diagnosing acute sinusitis [6].

Today, the diagnosis of sinusitis is mostly based on the medical history of the patient. Sometimes sinusitis is diagnosed using X-ray, CT scans and ultrasound. Due to the difficult nature of sinusitis diagnosis, unnecessary antibiotic treatment is very common [11]. Therefore there is a great need for simple, non-intrusive alternatives or complementary methods to detect sinusitis [11]. Detection of sinusitis via images is an alternative towards achieving non-intrusive detection of sinusitis.

Images of sinusitis are taken either using X-ray, CT-scan or MRI. Images have to be interpreted by doctors manually and this gives room for inconsistency or in some cases, inaccuracy. Interpretations may differ from one doctor to another. This variability can be caused by different levels of experience and accuracy as well as different interpretation of the data [12]. Variability may be particularly high in paranasal sinuses due to their complex anatomy [12]. Variability in interpretation of images affects efficient detection and diagnosis of sinusitis through images.

Image segmentation is important as the results of segmentation are used for diagnosis and surgical planning. At present, manual segmentation and semi-automatic segmentations are used. However, manual segmentation and semi-automatic are not useful for everyday surgical workflow because they take too much time [13]. Fully automatic and reproducible segmentation algorithms are needed for segmentation of paranasal sinuses and nasal cavity [13].

In a nutshell, due to the difficult diagnosis of sinusitis, there is a great need for efficient yet non-intrusive detection method. This can be achieved through detection of sinusitis through images. Automatic and reproducible algorithms should be developed for more efficient diagnosis.

1.3 Objective of Study

The objective of this Final Year Project is to develop an algorithm for computerized segmentation of CT sinus images. The input images will be segmented into three distinct regions; the bone, the mucous and the hollow areas of the sinuses. Separating the images into the different parts will allow extraction of useful information for subsequent applications.

1.4 Scope of Study

Segmentation is performed on images of healthy sinuses and images of sinuses with sinusitis to study the different results generated by the two different cases. The segmented images are used for the detection and grading of sinusitis and the 3-D reconstruction of sinus models.

CHAPTER 2
LITERATURE REVIEW

2.1 Sinusitis Detection Methods

The method most widely used now is by looking at patient's medical history and symptoms of sinusitis present. Studies are being carried out in search for more efficient and accurate way to detect sinusitis. The main goal of these studies is to develop a non-intrusive method to detect sinusitis.

One of the non-invasive methods developed is a hand held ultrasonic unit to detect maxillary sinus called Sinuscan. This device operates on the basis of back wall echo. The sinus cavities of humans are well accessible from the front and the back wall of the cavity is rather smooth and a good reflector of ultrasound [14]. Therefore, presence of fluid can be deduced from the back wall echo of the cavity. However, this method can only be used for detection of maxillary sinusitis where ultrasound can be transmitted through the nose as shown in figure 3 (adapted from [14]).

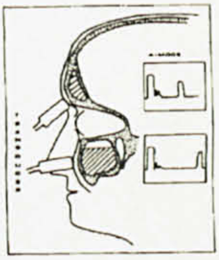


Figure 4: Operation of Sinuscan

Another method being studied is the detection of sinusitis using diode laser gas absorption spectroscopy. Simulations were done using the Monte Carlo concept and experiments were carried out on a healthy volunteer. In the study, the results from the experiments and the simulations show a good agreement for both tissue-like phantom measurements and the measurements of a healthy volunteer [11]. The results indicate that it is possible to detect sinusitis at an early stage by studying gas transport between the nasal cavity and the sinuses [11]. This method is still in research stage.

Perhaps the most widely used method for non-intrusive detection of sinusitis is the use of images obtained from medical imaging techniques such as X-ray, CT scan and MRI scan. Medical images are able to show blockage of sinus cavities and the locations of blockage and are used for surgical and treatment planning. There is room for improvement in this area as image processing methods can be implemented on these images to create more accurate and detailed images.

In this project, sinusitis detection via paranasal sinus images is studied. Image processing methods will be used to enhance images and to extract important features for the detection of sinusitis.

2.2 Imaging Techniques Used in Sinusitis Detection

There are many methods used in diagnosis of sinusitis. X-ray, CT-scan and MRI are imaging techniques used to provide images of sinuses in the diagnosis of sinusitis. In this section, these three imaging techniques are discussed and compared in terms of their effectiveness in diagnosing different types of sinusitis, operating costs, accessibilities and radiation doses.

2.2.1 Effectiveness

Radiographs indicate sinusitis through mucosal thickening or complete opacification of maxillary sinus. Figure 4 (adapted from [4]) shows the mucosal thickening of the sinus. Mucosal thickening is indicated by the presence of fluid in the sinus. Depending on the criteria used to diagnose sinusitis on a plain radiograph, estimates of sensitivity of radiographs in detecting sinusitis ranged from 0.41 to 0.90 while estimates of specificity ranged from 0.61 to 0.85 [15]. Imaging studies that included "mucous membrane thickening" as a criterion for sinusitis were more sensitive but less specific than studies defining positive radiographs as "opacification of sinus" [15]. In the diagnosis of acute sinusitis, the positive predictive values of x-rays using opacification and air-fluid levels as end points is 80 to 100 percent, but the sensitivity is low since only 60 percent of patients with acute sinusitis have opacification or air-fluid levels [6]. As of now, sinus X–rays have limited utility in the diagnosis of acute sinusitis and are of no value in the evaluation of chronic sinusitis [16]. However, they may be helpful in uncertain or recurrent cases [6].

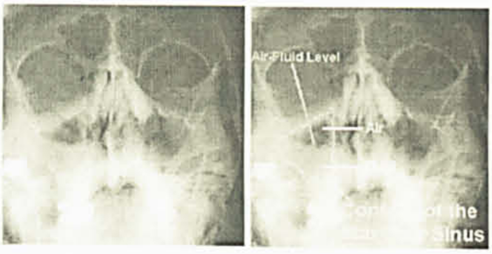


Figure 5: Sample X-ray (Water's view) images of maxillary sinus

CT scan is more useful in visualising sinusitis and more commonly used by physicians. CT scan helps define the location, extent and character of the lesion [17]. CT scans are more sensitive compared to X-rays. However, the specificity of CT scan in detecting sinusitis is still unclear. Sinus CT scanning has a high sensitivity but a low specificity for demonstrating acute sinusitis [6]. In children and adults without symptoms of sinusitis, the prevalence of sinusitis signs on CT images is 45% [15]. CT is preferred for preoperative evaluation of the nose and paranasal studies [6], and for patients whom surgery is being contemplated or for whom chronic sinusitis is a concern [6]. In sphenoid sinusitis, CT scan is the main tool for diagnosis. CT scan establishes the presence of sphenoid disease and provides information on bony erosion [18]. An air-fluid level usually is observed in acute disease, while complete opacification is more common in chronic disease [18]. In the setting of acute sinusitis, a CT scan establishes the anatomy of the sphenoid, including the size of the cavity and the intersinus septum [18]. Figure 5 (adapted from [4]) shows examples of CT scan images.

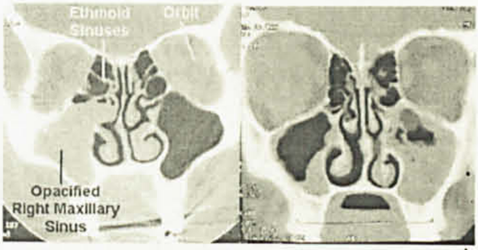


Figure 6: Sample CT images of maxillary sinus

MRI is more sensitive than a CT scan. MRI is better for imaging of soft tissues, and therefore very sensitive for diagnosis of soft tissue disease in the frontal, maxillary and sphenoid sinuses [15]. However, like CT scan, the specificity of MRI images is also unclear. In children and adults without symptoms of sinusitis, the prevalence of sinusitis signs on MRI images is 42% [15]. In some cases, MRI may help further define the nature and extent of a lesion [17]. In diagnosing sphenoid sinusitis, MRI is useful in evaluating the relationship of the sphenoid to its surrounding structures [18]. Figure 6 (adapted from [4]) shows examples of MRI scan images.

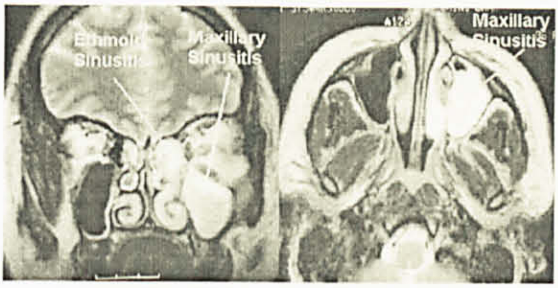


Figure 7: Sample MRI images of maxillary and ethmoid sinusitis

As a conclusion, X-rays are more useful in diagnosing acute sinusitis, CT scans help in diagnosing both acute sinusitis and chronic sinusitis but are more helpful for chronic sinusitis while MRI images are very sensitive in imaging soft tissues.

2.2.2 Operating Cost

A study conducted by Clinical Research Center (CRC) of Ministry of Health Malaysia (MOH) revealed the cost per unit output that is incurred on hospitals for each imaging modality. The cost per unit output consists of the cost of the equipment, labour cost and overhead cost [19]. The costs are summarized below in Table 1.

Table 1: Cost of imaging modalities in hospitals

	X-ray	**CT scan**	**MRI**
Cost per unit output	33	209	893

2.2.3 Accessibility

The same study conducted by CRC, MOH also gives details on the accessibility of the three imaging modalities. This study was conducted on all MOH hospitals, categorised into three types; state hospitals (type A), district hospitals with resident radiologists (type B) and district hospitals without resident radiologists (type C). X-ray facility is available in all hospitals, CT scan facility is available in 93% of type A hospitals and 22% of type B hospitals while MRI is available in 21% of type A hospitals. The availability of X-ray scans, CT scans and MRI scans in these three types of hospitals are summarised Table 2. X-ray procedure takes shorter time compared to CT scans and MRI scans. CT scans and MRI take around 30 minutes to 2 hours to complete while X-ray only takes a few minutes.

Table 2: Availability of imaging modalities in hospitals

	X-ray	CT scan	MRI
State hospitals	100%	93%	21%
District hospitals with resident radiologists	100%	22%	NA
District hospitals without resident radiologists	100%	NA	NA

Note: NA = Not Available

2.2.4 Radiation Dose

Radiation dose are measured in terms of effective dose. Effective dose refers to the dose averaged over the entired body. The effective radiation dose for a sinus CT scan is 0.6mSv [20]. CT scans essentially use the same waves as X-ray therefore both X-ray and CT scans expose patients to similar amount of radiation. MRI does not use these waves and is considered much less harmful. Recent development has managed to reduce the amount of radiation necessary for diagnostic imaging without compromising the image quality [21]. Therefore, radiation exposure is minimal.

2.2.5 Comparison of each imaging modality

The imaging modalities are compared in Table 3 based on the four factors which have been discussed in the previous sections. This project uses CT images as CT scan is the most used imaging modality in imaging sinuses. CT scans facilities are also commonly available despite being expensive.

Table 3: A comparison of X-ray, CT scan and MRI

	X-ray	**CT scan**	**MRI**
Effectiveness	Not that effective	Effective and commonly used	Not that effective
Cost	Cheap	Expensive	Very expensive
Accessibility	Widely available	Commonly available	Not commonly available
Radiation dose	Present	Present	Not present

Image processing methods will be applied on the CT scan images to achieve the objective of this study.

2.3 Image Enhancement Methods

2.3.1 Noise Reduction

The three types of noise reduction techniques are noise reduction using linear filters, order-statistics filter and adaptive filters.

Linear filtering is filtering in which the value of an output pixel is a linear combination of the values of the pixels in the input pixel's neighborhood. An example of a linear filter is an average filters. Average filters are well suited for random noise like Gaussian or impulse noise [22].

Order-statistics filters are spatial filters whose response is based on ordering the pixels contained in the image area encompassed by the filter [22]. Examples of order-statistics filters include median filter, max and min filters and midpoint filter. Out of these filters, median filters are popular because they provide excellent noise-reduction capabilities, with considerably less blurring than linear smoothing filters of similar size [22].

Adaptive filters are filters whose behaviour changes based on statistical characteristics of the image inside the filter region [22]. Therefore, adaptive filters are capable of performance more superior to that of linear filters and order-statistics filters. However, the price paid for improved filtering power is an increase in filter complexity [22].

2.3.2 Contrast Enhancement

Contrast enhancement can be performed by equalizing the histogram of the image. The histogram of an image is plot of gray level intensities against number of pixels. The histogram is a discrete function of $h(r_k) = n_k$, where r_k is the kth gray level and n_k is the number of pixels in the image having gray level r_k [22]. Histogram equalization (HE) is the process of transforming the original histogram of the image to a histogram with uniform distribution of pixels for all gray values.

Histogram equalization can be performed on the histogram of the entire image. This is referred to as Global Histogram Equalization (GHE). Another method of HE is the Contrast-Limited Adaptive Histogram Equalization (CLAHE) method. This method examines the histogram in a region centered at a pixel and sets the displayed intensity at that pixel as the rank of that pixel's intensity at its histogram [23]. In other words, the method divides the entire image into regions and equalizes the histograms of the individual regions to achieve better contrast. In MATLAB, the regions are then combined using bilinear interpolation to eliminate artificially induced boundaries.

2.4 Multilevel Thresholding Segmentation Methods

A greylevel image has an intensity range depending on how many bits are used to represent the intensity range from black to white. For example, if 8 bits are used, the histogram shows intensity range from 0 (black) to 255 (white). Image pixels are distributed across the intensity range. Multilevel thresholding methods partition an image into regions. This is done by finding groups of pixels with similar properties and assigning the pixels within a group with a definite intensity value. A region within an image is then a group of pixels having the same intensity value.

Multilevel thresholding can be performed based on two interesting properties of an image histogram; symmetry and duality [24]. As thresholding methods concern with the finding of peaks and valleys, this method finds the peaks based on symmetry that the hillsides of each hill are symmetric about central curve and valleys based on duality that peaks and valleys are opposite [24]. This method is computationally fast compared to traditional methods [24].

The Growing Time Adaptive Self-Organizing Map (GTASOM) uses neural network for the peak finding process [25]. The GTASOM is first trained by the grey levels of the given image [25]. The converged weights of the neurons are then used by peak finding process for image segmentation [25].

Automatic multilevel threshold selection can also be realised based on maximum entropy theorem [26]. This method gives a new definition to entropy of an image and uses an equivalent equation of the existing entropy equation [26]. This method overcomes drawbacks of existing entropy methods [26]. The simple algorithm calculates thresholds more quickly, reduces computational complexity and provides better stabilisation [26].

CHAPTER 3
METHODOLOGY

3.1 Research Methodology

This study used CT scan sinus images as input images. Image enhancement was first performed on the images. Noise reduction and contrast enhancement techniques were applied on the images. Then, multilevel thresholding algorithms were developed for the segmentation of the images into three regions of interest. The segmented images were used in the grading of sinusitis and the 3-D reconstruction of sinus models. The research methodology is summarised in the following flowchart. The Gantt Chart detailing the schedule of this project is presented in Appendix I.

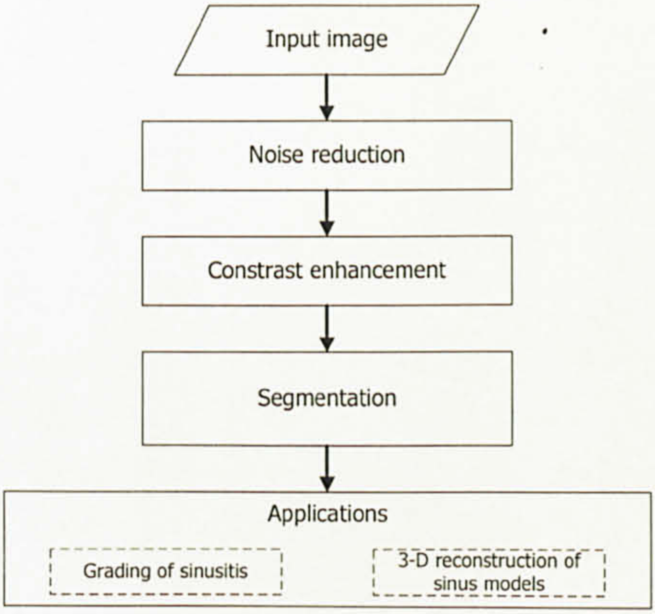


Figure 8: Research methodology

3.2 Tools

3.2.1 Software

The software used to perform simulations is the MATLAB software. The source codes for each algorithm were written and validated in MATLAB.

3.3 Image Enhancement

3.3.1 Noise Reduction

Median filtering was used to reduce noise in the images. Median filters are spatial filters where the median of the points encompassed in a filter window is chosen as the center value of that filter window. Median filtering was chosen so that noise can be reduced while preserving the edges in the original images.

3.3.2 Contrast Enhancement

Contrast enhancement was performed using the Contrast Limited Adaptive Histogram Equalisation (CLAHE) method. CLAHE divides the median filtered images into regions. Histogram equalisation was then carried out on the histograms of each individual region. This process evens out the distribution of grey level values, making the hidden features of the image more visible [27].

3.4 Image Segmentation

In order to perform segmentation on the sinus images, the behaviour of the images must first be studied. Image histograms of the input images were analysed. The image histogram in Figure 9 shows the pixels distribution across the grey levels. The grey levels are represented with 8 bits, therefore, the grey level intensities start with 0 (black) up to 255 (white). As can be seen in the image histogram in, the pixels are clustered at three different areas of grey level. The image histogram shows three hills and two valleys. The first hill starting from black indicates the hollow area, the second hill at grey indicates the mucous area and the third hill ending with white indicates the bone area.

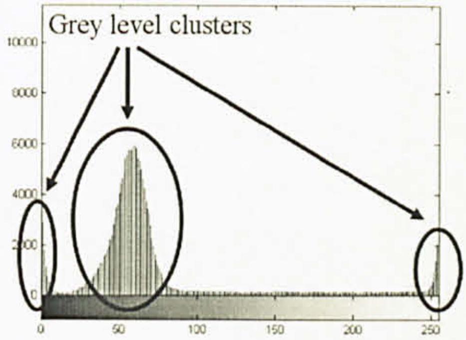


Figure 9: Image histogram

Multilevel thresholding algorithms were used to separate the three distinct regions of the images; the bone region, mucous region and hollow region. Two multilevel thresholding algorithms were developed in this project. The algorithms share similar working steps. Both the algorithms first search for three hill peaks, P_1, P_2 and P_3. After obtaining the peaks, the algorithms then perform calculations in search of two threshold values, T_1 and T_2; one in between the first and second clusters and another one in between the second and third clusters. The thresholds partition the image into the three regions. The pixels located before the T_1 will be converted into black pixels having values of 0, the pixels found between T_1 and T_2 will be converted into grey pixels having values of 127 and the pixels located after T_2 will be converted into white pixels having values of 255. Figure 10 shows the two threshold values that need to be calculated.

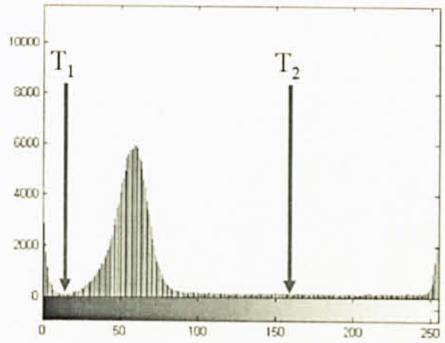


Figure 10: T_1 and T_2 are the threshold values to be calculated

The difference between Algorithm 1 and Algorithm 2 is the calculation to obtain the threshold values. Algorithm 1 uses the middle point between the two peaks as a threshold while Algorithm 2 determines a threshold as the mean grey level value between the grey level clusters. Table 4 shows the pseudo-codes of each algorithm along with the corresponding formulas used to obtain the threshold values.

Table 4: Pseudo-codes of multilevel thresholding algorithms

Algorithm 1	Algorithm 2
1. Search for three peaks from histogram, P_1, P_2 and P_3. 2. Determine the grey level at each peak, G_1, G_2 and G_3. 3. Calculate thresholds, T_1 and T_2. $T_n = \frac{G_n + G_{n+1}}{2}$ 4. Segment image into three regions using the calculated thresholds. Grey level < T_1 => black (0) T_1 < Grey level < T_2 => grey (127) Grey level > T_2 => white (255)	1. Search for three peaks from histogram, P_1, P_2 and P_3. 2. Select three initial thresholds. (Initial thresholds will partition image into three regions). 3. Calculate the average grey level in each region, AG_1, AG_2 and AG_3. $AG_n = \frac{\sum (\text{I x no. of pixels at I})}{\text{total number of pixels in region}}$ where I is intensity levels present in region 4. Calculate thresholds, T_1 and T_2. $T_n = \frac{AG_n + AG_{n+1}}{2}$ 5. Segment image into three regions using the calculated thresholds. Grey level < T_1 => black (0) T_1 < Grey level < T_2 => grey (127) Grey level > T_2 => white (255)

The source code of Algorithm 1 is attached in Appendix II while the source code of Algorithm 2 is attached in Appendix III.

3.5 Grading of Sinusitis

The grading of sinusitis was performed on the sinus images segmented with Algorithm 2. This process used the seeded region growing method where seeds are placed on the mucous areas of the sinuses to obtain the total area of the sinuses affected by sinusitis. Seeds are also placed on the hollow areas of the sinuses to obtain the total area of the sinuses not affected by sinusitis. These values are then compared with the total area of the sinuses to evaluate the severity factor of the sinusitis. The severity factor as shown in Equation (1) is given by the ratio of the total area of sinuses affected by sinusitis versus the total area of sinuses and ranges from 0 to 1. The further this ratio is from 0, the more affected the sinuses are with sinusitis. Extracting the mucous areas and the hollow areas ensures that grading can be performed on sinuses of different sizes, making this method robust.

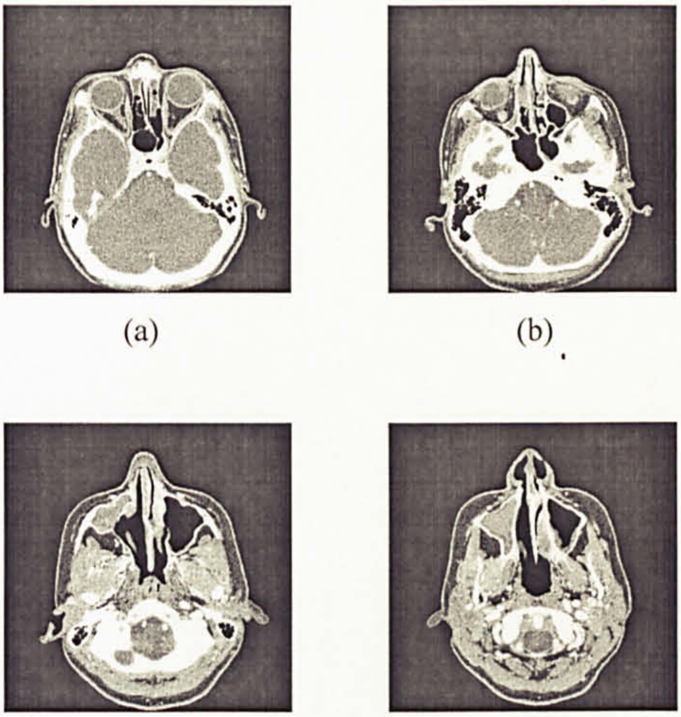
$$\text{severity factor} = \frac{\text{total area of mucous area}}{\text{total area of sinuses}} \qquad (1)$$

where

$$\text{total area of sinuses} = \text{total area of mucous areas} + \text{total area of hollow areas}$$

3.6 3-D Reconstruction of Sinus Model

The 3-D model of the sinuses was constructed by first segmenting the input images with Algorithm 2. The input images for the 3-D reconstruction have to be slices of CT scan images taken from the same angle. Four continuous slices as shown in Figure 11 were obtained and used for the sinus reconstruction. These images were then stacked bottom up. 3-D reconstruction was done using MATLAB commands. From the 2-D slices, the volume between the slices were interpolated and rendered to form the 3-D model.



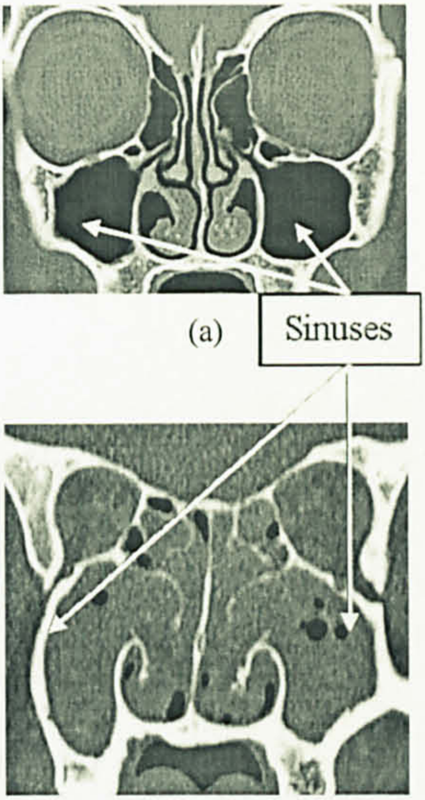
(a) (b)

(c) (d)

Figure 11: Input images for the 3-D reconstruction of sinus model

CHAPTER 4
RESULTS AND DISCUSSIONS

Simulations were performed on both images of healthy sinuses and sinuses with sinusitis. Based on Figure 12, the healthy sinuses are entirely black, indicating the absence of mucous while the sinuses with sinusitis are grey with patches of black, indicating a strong presence of mucous.



(a)

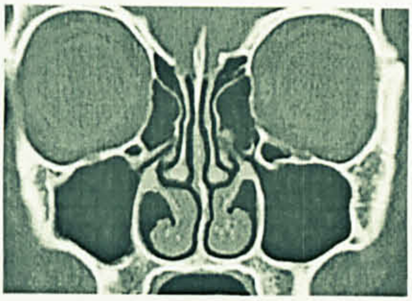
(b)

Figure 12: (a) Image of healthy sinuses (b) Image of sinuses with sinusitis

4.1 Image Enhancement

4.1.1 Noise Reduction

Median filtering was able to remove noise, without blurring the edges in the images. The images are less grainy after median filtering. The results of this noise reduction technique are shown in Figure 13.



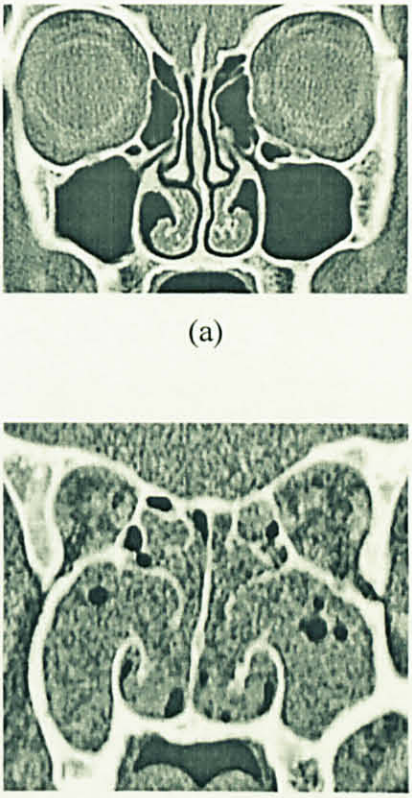
(a)

(b)

Figure 13: Results of median filtering (a) Image of healthy sinuses (b) Image of sinuses with sinusitis

4.1.2 Contrast Enhancement

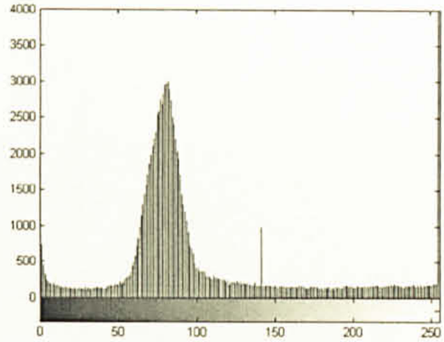
CLAHE managed to distribute the image pixels more evenly across the entire intensity level range, improving the contrast of the image. As a result, the image histogram was also smoothened. Figure 14 shows the results of CLAHE while Figure 15 shows the flattened image histogram of the image with healthy sinuses due to CLAHE.



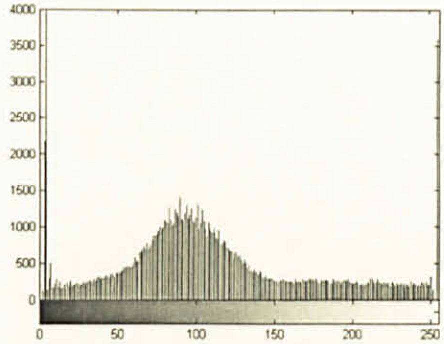
(a)

(b)

Figure 14: Results of CLAHE (a) Image of healthy sinuses (b) Image of sinuses with sinusitis



(a)

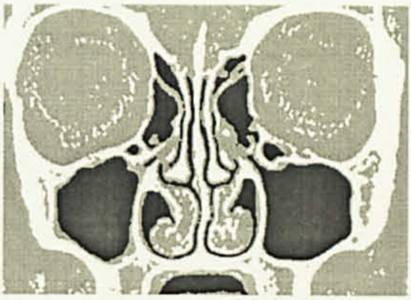


(b)

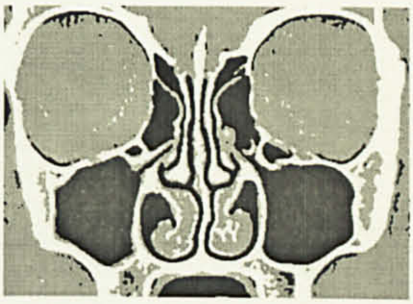
Figure 15: Histogram of image with healthy sinuses is smoothened after image enhancement resulting in better contrast (a) Original histogram (b) Flattened histogram

4.2 Image Segmentation

The segmentation algorithms developed in this study were successful in segmenting the images into the three regions; the bone region, the mucous areas and the hollow areas of the sinuses. Only three intensity levels are present in the segmented image; 0 (black) for the hollow areas, 127 (grey) for the mucous areas and 255 (white) for the bone areas. Algorithm 2 segmented the images with less artefacts and less disjointed areas compared to Algorithm 1, hence giving a more accurate representation of the different regions in the images. Figure 16 shows the segmentation results of healthy sinuses while Figure 17 shows the segmentation results of sinuses with sinusitis.



(a)



(b)

Figure 16: Results of segmentation for healthy sinuses (a) Image segmented using Algorithm 1 (b) Image segmented using Algorithm 2

(a)

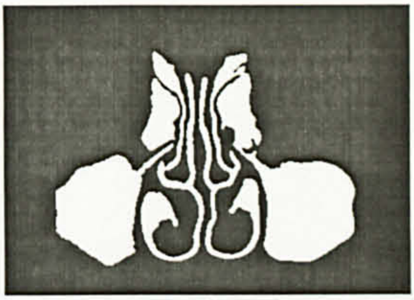
(b)

Figure 17: Results of segmentation for sinuses with sinusitis (a) Image segmented using Algorithm 1 (b) Image segmented using Algorithm 2

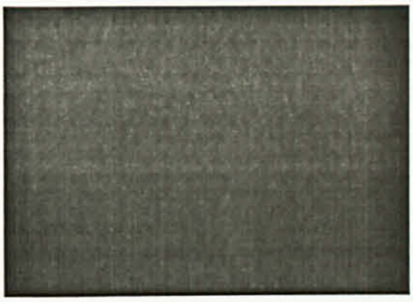
Comparing the results for the healthy sinuses and the sinuses affected with sinusitis, there are more black areas in the image of healthy sinuses. The image of sinuses of sinusitis contains more grey areas, indicating presence of mucous in the sinuses and therefore sinusitis. The segmentation algorithms were able to differentiate between healthy sinuses and sinuses with sinusitis.

4.3 Grading of Sinusitis

The grading was performed on both image of healthy sinuses and sinuses with sinusitis. The calculated severity factor for the healthy sinuses is 0 as there are no mucous areas in the sinuses. The calculated severity factor for the healthy sinuses is 0 as there are no mucous areas in the sinuses. The calculated severity factor for the sinuses with sinusitis is 0.88, indicating serious sinusitis. .The calculations matched the diagnosis of both the healthy sinuses and the sinuses with sinusitis. Besides the calculated severity factor, the binary output images of this process show very clearly the mucous and hollow areas of the sinuses. Figure 18 shows the results for healthy sinuses while Figure 19 shows the results for sinuses with sinusitis.

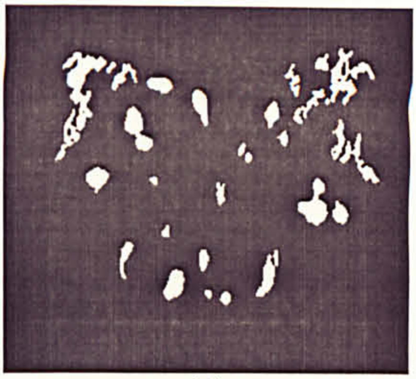


(a)

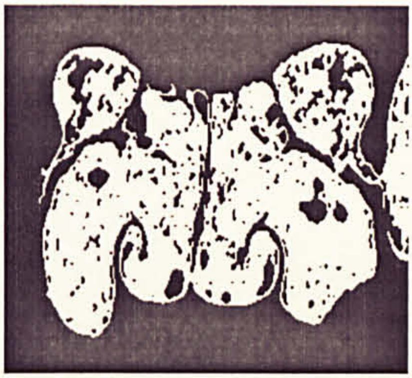


(b)

Figure 18: Extracted areas from image of healthy sinuses (a) Extracted hollow areas (b) Extracted mucous areas



(a)



(b)

Figure 19: Extracted areas from image of healthy sinuses (a) Extracted hollow areas (b) Extracted mucous areas

4.4 3-D Reconstruction of Sinus Model

Figure 20 shows the 3-D model constructed from the images shown in Figure 11. The 3-D model would have been more accurate if more slices of CT scan sinus images were obtained. The 3-D model depicts the volume of the three different parts; the hollow, the mucous and the bone regions. This 3-D model helps clinicians visualise the volume of the sinuses and is especially useful when cases of severe sinusitis need to be treated with sinus surgery. Surgeons will be able to view the inner anatomy of the sinuses and their structure before a surgery. This greatly facilitates in the planning of the surgery.

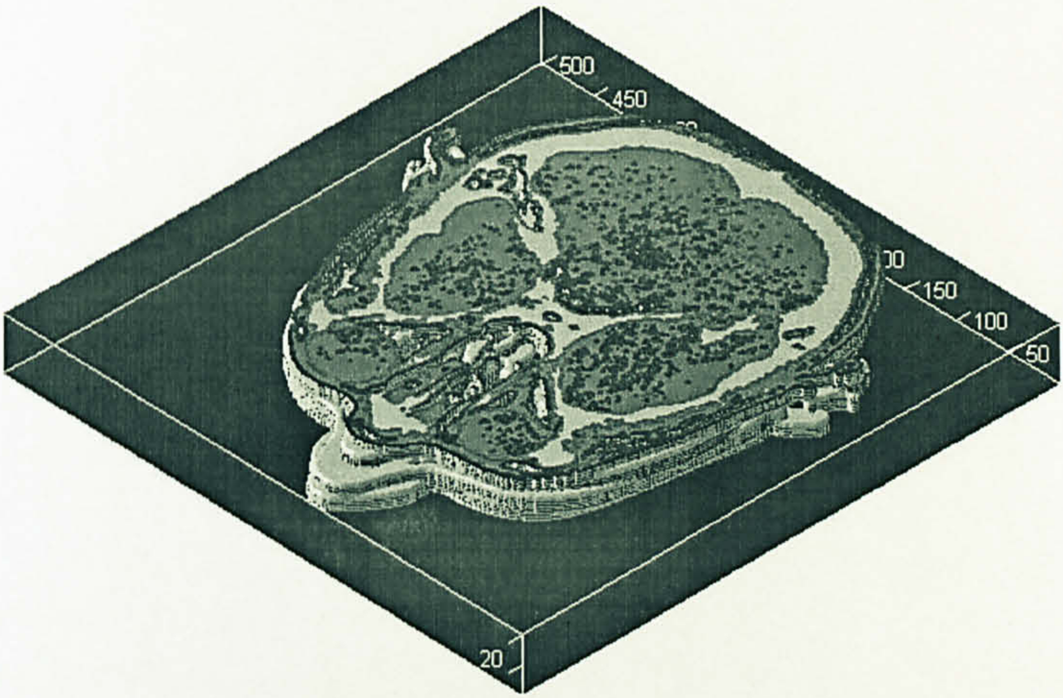


Figure 20: 3-D sinus model

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

As a conclusion, image processing techniques applied on the images were able to fulfill the objective of this study which is computerised segmentation of the sinus images into the three distinct regions; the hollow, mucous and bone regions of the sinuses. Median filtering was used to reduce noise while the CLAHE method was used to improve the contrast of the image. Multilevel thresholding algorithms were developed for the segmentation of the images. The three important regions in the images are clearly differentiated by the segmentation algorithms. The segmented images are used to evaluate the severity factor of sinusitis by extracting the mucous areas and the hollow areas in the images. A 3-D model of the sinuses was also constructed.

This study presented the applications of the the segmented images which are the grading of sinusitis and the 3-D model of the sinuses. These applications greatly contribute to the healthcare industry by facilitating the detection, diagnosis and surgical planning of sinusitis. Imaging techniques applied in this area present a highly non-intrusive method of detecting and diagnosis of sinusitis, which is important for the comfort of patients. This pioneering work shows a promising beginning in the area of automated detection and classification of sinusitis and robot-assisted sinus surgery using the 3-D model.

5.2 Recommendations

This project can further be developed to bring more benefits to the healthcare industry. To investigate the clinical usefulness of the approaches presented in this report, clinical trials should be conducted for various cases of sinusitis. Clinical trials will provide more results, therefore benchmarks can be set for more accurate analysis in the future.

Image enhancement and segmentation may be improved for more precise segmentation results. This study has explored algorithms for multilevel thresholding. More methods of segmentation should be applied on the images to compare the results of each method. Further development would strengthen the prospect of this approach in the grading of sinusitis.

The 3-D model should be enhanced to enable the volume calculation of each individual region in the sinuses. This will provide surgeons with an exact model of the sinuses. Surgical planning and decision-making can be done more effectively. Carrying out more development and growth in this area will also open up the path for robot-assisted sinus surgery in the future.

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APPENDICES

APPENDIX I: GANTT CHART OF STUDY

	2008						2009					
TASK	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
Literature review, planning, obtain images												
Noise reduction												
Contrast enhancement												
Segmentation												
Grading of sinusitis												
3-D reconstruction of sinus models												

APPENDIX II: MULTILEVEL THRESHOLDING ALGORITHM 1

```
echo off
close all
clear all

image = imread ('image1.jpg');
image_greyscale = rgb2gray(image);
figure, imshow(image_greyscale);
title('Original image');

image_greyscale = medfilt2(image_greyscale);
figure, imshow(image_greyscale);
title('After median filter');

image_greyscale = adapthisteq(image_greyscale);
figure, imshow(image_greyscale);
title('After CLAHE');

%Getting number of pixels at each grey level
num_pixels = zeros(1, 256);
for greylevel = 0:255
    x = greylevel + 1;
    num_pixels(x) = 0;
    for r = 1:512
        for c = 1:512
            if (image_greyscale(r,c) == greylevel)
                num_pixels(x) = num_pixels(x) + 1;
            end
        end
    end
end

%Checking total number of pixels
sum = 0;
for vector = 1:256
    sum = num_pixels(x) + sum;
end

%Finding the global peak and its location
peak_one = 0;
peak_one_greylevel = 0;
for y = 1: 256
    if (num_pixels(y) > peak_one)
        peak_one = num_pixels(y);
        peak_one_greylevel = y;
    end
end

%Finding second peak
peak_two = 0;
peak_two_greylevel = 0;
for y = 1: 256
```

```
    if ((num_pixels(y) > peak_two) && (num_pixels(y) < peak_one))
        peak_two = num_pixels(y);
        peak_two_greylevel = y;
    end
end

%Finding the third peak
peak_three = 0;
peak_three_greylevel = 0;
for y = 1: 256
    if ((num_pixels(y) > peak_three) && (num_pixels(y) < peak_two))
        peak_three = num_pixels(y);
        peak_three_greylevel = y;
    end
end

%Sort greylevels of peaks ini ascending order
peak_greylevel = zeros(1, 3);
peak_greylevel(1) = peak_one_greylevel;
peak_greylevel(2) = peak_two_greylevel;
peak_greylevel(3) = peak_three_greylevel;
peak_greylevel = sort(peak_greylevel, 'ascend');

%Partitioning the grey levels
partition = zeros(1,2);
for z=1:2
    partition(z) = (peak_greylevel(z+1) - peak_greylevel(z)) / 2 +
peak_greylevel(z) - 1;
end
partition = round(partition);

%Segmentation
for r = 1:512
    for c = 1:512
        if (image_greyscale(r,c) >= 0 && image_greyscale(r,c) <=
partition(1))
            image_greyscale(r,c) = 0;
        elseif (image_greyscale(r,c) > partition(1) &&
image_greyscale(r,c) <= partition(2))
            image_greyscale(r,c) = 127;
        else
            image_greyscale(r,c) = 255;
        end
    end
end

figure, imshow(image_greyscale);
```

APPENDIX III: MULTILEVEL THRESHOLDING ALGORITHM 2

```
echo off
close all
clear all

image = imread ('image1.jpg');
image_greyscale = rgb2gray(image);
figure, imshow(image_greyscale);
title('Original image');

image_greyscale = medfilt2(image_greyscale);
figure, imshow(image_greyscale);
title('After median filter');

image_greyscale = adapthisteq(image_greyscale);
figure, imshow(image_greyscale);
title('After CLAHE');

%Getting number of pixels at each grey level
num_pixels = zeros(1, 256);
for greylevel = 0:255
    x = greylevel + 1;
    num_pixels(x) = 0;
    for r = 1:512
        for c = 1:512
            if (image_greyscale(r,c) == greylevel)
                num_pixels(x) = num_pixels(x) + 1;
            end
        end
    end
end

%Checking total number of pixels
sum = 0;
for vector = 1:256
    sum = num_pixels(x) + sum;
end

%Finding the global peak and its location
peak_one = 0;
peak_one_greylevel = 0;
for y = 1: 256
    if (num_pixels(y) > peak_one)
        peak_one = num_pixels(y);
        peak_one_greylevel = y;
    end
end

%Finding second peak
peak_two = 0;
peak_two_greylevel = 0;
```

```
for y = 1: 256
    if ((num_pixels(y) > peak_two) && (num_pixels(y) < peak_one))
        peak_two = num_pixels(y);
        peak_two_greylevel = y;
    end
end

%Finding the third peak
peak_three = 0;
peak_three_greylevel = 0;
for y = 1: 256
    if ((num_pixels(y) > peak_three) && (num_pixels(y) < peak_two))
        peak_three = num_pixels(y);
        peak_three_greylevel = y;
    end
end

%Sort greylevels of peaks ini ascending order
peak_greylevel = zeros(1, 3);
peak_greylevel(1) = peak_one_greylevel;
peak_greylevel(2) = peak_two_greylevel;
peak_greylevel(3) = peak_three_greylevel;
peak_greylevel = sort(peak_greylevel, 'ascend');

%Selecting initial thresholds
initial_threshold = zeros(1,2);
for z=1:2
    initial_threshold(z) = (peak_greylevel(z+1) - peak_greylevel(z))
/ 2 + peak_greylevel(z);
end
initial_threshold = round(initial_threshold);

%Calculating threshold
g1 = 0; n1 = 0; G1 = 0;
g2 = 0; n2 = 0; G2 = 0;
g3 = 0; n3 = 0; G3 = 0;
threshold = zeros(1,2);
threshold(1) = initial_threshold(1);
threshold(2) = initial_threshold(2);

temp1 = 0;
temp2 = 0;

while (temp1 ~= threshold(1) && temp2 ~= threshold(2));
temp1 = threshold(1);
temp2 = threshold(2);
for a = 1:256
    if (a <= threshold(1))
        g1 = num_pixels(a) * a + G1;
        n1 = num_pixels(a) + n1;
    elseif (a > threshold(1) && a <= threshold(2));
        g2 = num_pixels(a) * a + g2;
        n2 = num_pixels(a) + n2;
    else
        g3 = num_pixels(a) * a + g3;
        n3 = num_pixels(a) + n3;
```

```
    end
end

G1 = g1/n1; G2 = g2/n2; G3 = g3/n3;

threshold(1) = (G1 + G2) / 2;
threshold(2) = (G2 + G3) / 2;
end
%temp1 = threshold(1);
%temp2 = threshold(2);

threshold = round(threshold);

%Segmentation
for r = 1:512
    for c = 1:512
        if (image_greyscale(r,c) >= 0 && image_greyscale(r,c) <=
threshold(1))
            image_greyscale(r,c) = 0;
        elseif (image_greyscale(r,c) > threshold(1) &&
image_greyscale(r,c) <= threshold(2))
            image_greyscale(r,c) = 127;
        else
            image_greyscale(r,c) = 255;
        end
    end
end

figure, imshow(image_greyscale);
```

APPENDIX IV: GRADING OF SINUSITIS

```
echo off
close all
clear all

image = imread ('image1.jpg');

segmented = multiple_thresholding_2(image);
figure, imshow(segmented);

[rows cols] = size(segmented);

reply = input('Any mucous in sinuses? Y/N : ', 's');
if (reply == 'Y')
    mucous = rg(segmented,20);
    mucous_counter = 0;
    for r = 1:rows
        for c = 1:cols
            if (mucous(r,c) == 1)
                mucous_counter = mucous_counter + 1;
            end
        end
    end
else
    mucous = zeros(size(segmented));
    mucous_counter = 0;
end

reply = input('Any unaffected area in sinuses? Y/N : ', 's');
if (reply == 'Y')
    hollow = rg(segmented,20);
    hollow_counter = 0;
    for r = 1:rows
        for c = 1:cols
            if (hollow(r,c) == 1)
                hollow_counter = hollow_counter + 1;
            end
        end
    end
else
    hollow = zeros(size(segmented));
    hollow_counter = 0;
end

total = hollow + mucous;

total_counter = 0;
for r = 1:rows
    for c = 1:cols
        if (total(r,c) ~= 0)
            total_counter = total_counter + 1;
        end
    end
```

```
end

percentage_hollow = hollow_counter / total_counter * 100;
percentage_mucous = mucous_counter / total_counter * 100;

fprintf ('\nPercentage of unaffected area in sinuses: %3.2f ',
percentage_hollow);
fprintf ('\nPercentage of mucous area in sinuses: %3.2f ',
percentage_mucous);
fprintf ('\n\n');

figure, imshow(hollow);
figure, imshow(mucous);
figure, imshow(total);
```

APPENDIX V: 3-D RECONSTRUCTION OF SINUS MODEL

```
echo off
close all
clear all

image1 = imread ('slice1.jpg');
segmented1 = multiple_thresholding_2(image1);
figure, imshow(segmented1);
title ('Slice1 Segmented');

image2 = imread ('slice2.jpg');
segmented2 = multiple_thresholding_2(image2);
%figure, imshow(segmented2);
%title ('Slice2 Segmented');

image3 = imread ('slice3.jpg');
segmented3 = multiple_thresholding_2(image3);
%figure, imshow(segmented3);
%title ('Slice3 Segmented');

image4 = imread ('slice4.jpg');
segmented4 = multiple_thresholding_2(image4);
%figure, imshow(segmented4);
%title ('Slice4 Segmented');



%Loading images into array ct
[rows cols] = size(segmented1);
ct = zeros (rows, cols, 1, 16);

[ct(:,:,1,1)] = segmented4;
[ct(:,:,1,2)] = segmented4;
[ct(:,:,1,3)] = segmented4;
[ct(:,:,1,4)] = segmented4;
[ct(:,:,1,5)] = segmented3;
[ct(:,:,1,6)] = segmented3;
[ct(:,:,1,7)] = segmented3;
[ct(:,:,1,8)] = segmented3;
[ct(:,:,1,9)] = segmented2;
[ct(:,:,1,10)] = segmented2;
[ct(:,:,1,11)] = segmented2;
[ct(:,:,1,12)] = segmented2;
[ct(:,:,1,13)] = segmented1;
[ct(:,:,1,14)] = segmented1;
[ct(:,:,1,15)] = segmented1;
[ct(:,:,1,16)] = segmented1;

ct = squeeze(ct);

%Displaying one of images in array ct
pause;
image_num = 1;
```

```
image(ct(:,:,image_num))
axis image
colormap(bone);

x = xlim;
y = ylim;

%Contour slicing image
pause;
contourslice(ct,[],[],image_num)
axis ij
xlim(x)
ylim(y)
daspect([1,1,1])
colormap(bone)

%Showing a few images in 3D
pause;
phandles =
contourslice(ct,[],[],[1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16]);
view(3);
axis square
set(phandles,'LineWidth',2)
whitebg('k')

%Displaying an isosurface
pause;
ct_smooth = smooth3(ct);
hiso =
patch(isosurface(ct_smooth,5),'FaceColor','w','EdgeColor','none')

%Adding isocap
pause;
hcap =
patch(isocaps(ct_smooth,5),'FaceColor','interp','EdgeColor','none');
colormap(bone)

%Defining view
pause;
view(45,30)
axis square
daspect([1,1,.4])

%Add Lighting
lightangle(45,30);
set(gcf,'Renderer','zbuffer'); lighting phong
isonormals(ct_smooth,hiso)
set(hcap,'AmbientStrength',.6)
set(hiso,'SpecularColorReflectance',0,'SpecularExponent',50)
```